A Hybrid Renewable Energy Selection Model for Sustainable Development using Hesitant Fuzzy-Machine Learning Technique

A

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I, Virendra Singh Rana, declare that the synopsis entitled, "Hesitant Fuzzy-Machine Learning Novel Technique for the Selection of Renewable Energy Sources for Achieving Sustainable Development Goals in Uttarakhand" being submitted in the partial fulfillment of the requirement for the award of the degree of Doctor of Philosophy in Management under ICFAI Tech School, The ICFAI University, Dehradun during the academic year 2023-24.

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Abstract

The accomplishment of “Sustainable Development Goal Seven (SDG 7)” is vital for solving the energy crisis in the world which targets to provide “affordable and clean energy for everybody”. Uttarakhand is a state of diverse geographical, cultural and sensitive environment which lies in the northern part of India and is facing extreme energy demands. This research is proposing a novel hybrid model which integrates “Machine Learning (ML) techniques with Fuzzy-Multi Criteria Decision Making (MCDM)” approach in hesitant environment keeping in view to meet the “SDG 7” while considering Uttarakhand’s cultural and geographic diversity. The complex computation in the proposed model is developed and solved using python programming. Uttarakhand is the home of abundant renewable resources such as solar energy, wind energy, bio-energy, hydropower and solar thermal which makes it suitable for attaining the “SDG 7”. The prioritization of renewable energy sources requires a redefined and wide strategy which will include numbers of criteria and sub-criteria such as economic feasibility, environmental consequence, social recognition, technological viability, legal framework etc. The Machine Learning technique is used to filter or identify the final sub-criteria under the domain of main criteria from a survey list of the experts which plays crucial role in fulfilling the “SDG 7”. The hybrid decision making machine learning model is strengthen by using “Hesitant Fuzzy-MCDM” to reduce the complexities and uncertainties in the sustainable energy selection in Uttarakhand. The model ranks different renewable energy sources in Uttarakhand considering various main criteria and sub-criteria which are taken after going through the in depth literature survey and under the supervision of experts opinion. This novel approach provides a transparent and fair energy selection process which makes it a user friendly for the policymakers and the stakeholders. The proposed energy model ensures that the selection process is technically feasible and sustainable to environment, social, economic and other sectors. The outcomes of the study probable to meet the “SDG 7” in Uttarakhand through the proposed energy selection process which will enhance economic development, reduce the impressions on the environment and fulfill the energy requirement for all in the state. The proposed energy model provides a blueprint for the different areas (local/national) to achieve the “SDG 7” considering the various challenges associated with their regions.

Keywords: Sustainable Development Goals (SDGs), “Multi Criteria Decision Making (MCDM)”, “Renewable energy Source (RES)”, “Hesitant Fuzzy”, machine learning.

1. Introduction

The energy which is abstracted continuously from the natural sources and can sustain environment are called renewable energy. Renewable energies like solar energy do not have negative impact on the environment and considered as the clean source of energy.

1.1. Renewable energy in India

Renewable sources are available in abundant in nature such as wind, hydro, solar energy, geothermal energy, bio-energy, tidal energy etc. These sources of energy do not have any negative effect on environment on their use (Kumar. J & Majid, 2020). They can be replenished time to time. Renewable sources are known to be clean and green sources of energy. They are considered as the future of energy sector, due to their limitless presence in the nature. Due to lack of awareness and low technical advancement they are not being accessible to full use as they can. “Non - Renewable sources” are those sources of energy which produces a lot of “Green House Gases (GHG’s)” on their use (Amponsah et al., 2014). These sources are harmful for both nature and mankind. Also they are present in a limited quantity in nature. Fossil fuels and the related items comes under this category. These sources contribute about 81% of total energy supply. “Green House Gases (GHG’s)” like Carbon dioxide (CO_2), Methane (CH_4), CFC’s refrigerants, oxides of nitrogen etc. traps the solar radiation and hold it for a long time resulting in increasing the average temperature of the earth. Non-renewable sources like hydrocarbon fuels (petrol, diesel, kerosene etc.), coal, wood, cow dung, remains of the crop produces unburnt hydrocarbons, smoke, carbon monoxide, oxides of nitrogen and particulate materials which pollute the environment. The problem of pollution is the major challenge for all the nations in the world and it is a need of an hour to protect the environment by reducing the use of these non-renewable sources. This can be done by using renewable energy resources in place of it. The “United Nation” created 17 “Sustainable Development Goals (SDGs)” while considering the socio-economic and environment problem.(Nastasi et al., 2022) . The objectives of these “SDGs” is to protect the environment, improve the quality of life of the poor people, promote peace and harmony especially in the underdeveloped nation aligning with the rules and regulation set by the “United Nation”(Halkos & Gkampoura, 2021). The "Affordable and Clean Energy" which is the seventh goal of SDGs targets the “provision of electricity at a low cost to every home” without endangering the environment by 2030 (Büyüközkan et al., 2018a). “SDG 7” contains six indicators and five targets which also includes “encouraging access to research and investment in clean energy as well as

expanding and improving energy services for developed countries" are means of accomplishing the three result of "universal access to modern energy", "increasing the global percentage of renewable energy", and "doubling improvement in energy efficiency"(Agency et al., 2021).

1.1.1 Wind Energy

Wind is a source of renewable energy which has no adverse effect on the environment. It is a clean energy and is produced everywhere. A large amount of energy is being produced by wind everywhere and China is the leader amongst all the country.(Choi & Song, 2017) . It is harnessed by a device known as windmill which uses the kinetic energy of the wind for various purposes. India is also running many wind power project for the generation of sustainable energy. Because wind is an intermittent and site-specific energy source, a detailed "Wind Resource Assessment" is required for the identification of prospective spots. The government has created over 900 wind-monitoring stations across the country and released wind potential maps at 50m, 80m, 100m, 120m, and 150m above ground level through the "National Institute of Wind Energy (NIWE)". According to the most current study, the gross wind power potential is 695.50 MW at 120 meters and 1163.9 GW at 150 meters above ground level (*Ministry of New and Renewable Energy | Ministry of New and Renewable Energy | India*, n.d.). The majority of this potential occurs in the eight windy states listed below:

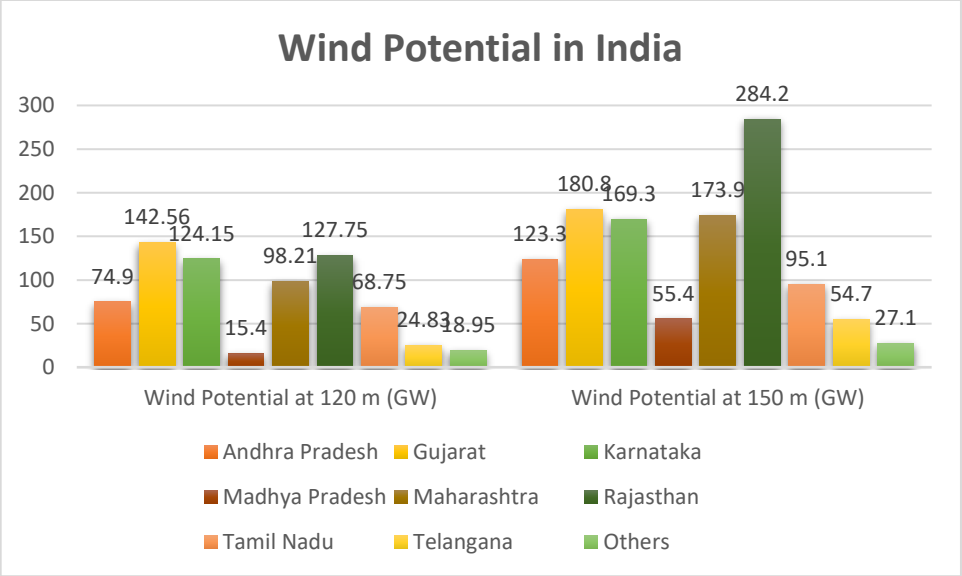


Figure 1: Wind potential in India (*Ministry of New and Renewable Energy*)

1.1.2 Solar Energy

Solar energy is the most important source of renewable energy as it is the cleanest of all and does not pollute the environment. It can be harness by various techniques like solar panels, solar concentrator, solar heater, Scheffler reflector etc. and is considered the future energy by many researcher (Rana et al., 2023). The future of solar energy is very demanding, as it is an alternate source of energy in the consideration of today's world and will create a lots of high paying jobs (Munir et al., 2010). Researchers are in continuous work devices for harnessing the solar energy which is economical and cost effective. India ranked fifth in the world in terms of solar PV installations. As of June 30, 2023, the installed capacity of solar power was approximately 70.10 GW. Ground-mounted solar projects account for 57.22 GW, rooftop solar projects account for 10.37 GW, and off-grid solar projects account for 2.51 GW (*Ministry of New and Renewable Energy | Ministry of New and Renewable Energy | India*, n.d.)**.** The "National Institute of Solar Energy (NISE)" has estimated the country's solar potential to be at 748 GW, assuming that Solar PV modules occupy 3% of the waste land area. Solar energy has been prioritized in India's National Action Plan on Climate Change, with the "National Solar Mission (NSM)" being one of the major Missions. NSM was released on January 11, 2010. The "Off-grid Solar PV Applications Programme" is one of the Ministry's oldest programmes, with the goal of offering solar PV-based applications in locations where grid power is either unavailable or unstable. The scheme covers applications such as "solar home lighting systems", "solar street lighting systems", "solar power plants", "solar pumps", "solar lanterns", and "solar study lamps". The 2010 "National Solar Mission" established a three-phase aim of 2000 MW equivalent of solar off-grid and decentralized PV installations by 2022. The three phases aims and achievements are discussed in Table 1(*Ministry of New and Renewable Energy | Ministry of New and Renewable Energy | India*, n.d.).

Table 1: Targets and achievement of solar mission(Ministry of New and Renewable Energy | Ministry of New and Renewable Energy | India, n.d.)

Phase	Period	Approved	Mounted
First	(2010-13)	252.5 MW	117 MW
Second	(2014-17)	713 MW	345.5 MW
Third	(2018-21)	20.09 MW	15.67 MW

1.1.3 Hydro-Energy

Hydro energy generation is one of the oldest method in which the kinetic energy of water is converted into mechanical energy to generate electricity with the help of hydraulic turbine. For this water from the high altitude falls on the turbine blades which rotates it (McLellan et al., 2012). Today's more the half of the world's energy consumption is fulfilled by production of energy through the hydro power plants only. It contributes 16% of the world's total energy consumption. Due to abundant presence of water in the earth, it is reliable to give energy source lifetime. It is also considered one of the cleanest and renewable source of energy. The energy from the hydro plant can be produced anytime throughout the year when required. Not only limited to benefit of energy production reserved water in the hydro power plant can also be used for irrigation purposes near the areas. The cost of energy produced from hydro is economical. The only drawback of Hydro Energy is that setup cost is very high, a lot of accuracy is required in setup process a small mistake can wipe out thousands of lives (Ullah et al., 2021) . Also it disturbs the economy and requires continuous flow of water throughout the year. Hydropower projects are characterized as large or small based on their size. Small Hydro Power plants are classified differently in different nations based on their size. Small hydro power facilities in India are those with a capacity of 25 MW or less. Prior to 1989, the "Ministry of Power" was in charge of hydropower. Plant capacity of 3MW and below was transferred to the "Ministry of New and Renewable Energy (MNRE)" in 1989. The "Hydro and Renewable Energy Department (HRED)", formerly known as the Alternate "Hydro Energy Centre (AHEC) of IIT Roorkee", assessed the estimated potential of 21133 MW from 7133 sites for power generation in the country from small / mini hydel projects and compiled it as the Small Hydro Database of July 2016. Arunachal Pradesh, Himachal Pradesh, Jammu and Kashmir, and Uttarakhand account for roughly half of this potential. Maharashtra, Chhattisgarh, Karnataka, and Kerala are other possible states. Through intimate connection with these states, special attention is paid to them(*Ministry of New and Renewable Energy | Ministry of New and Renewable Energy | India*, n.d.).

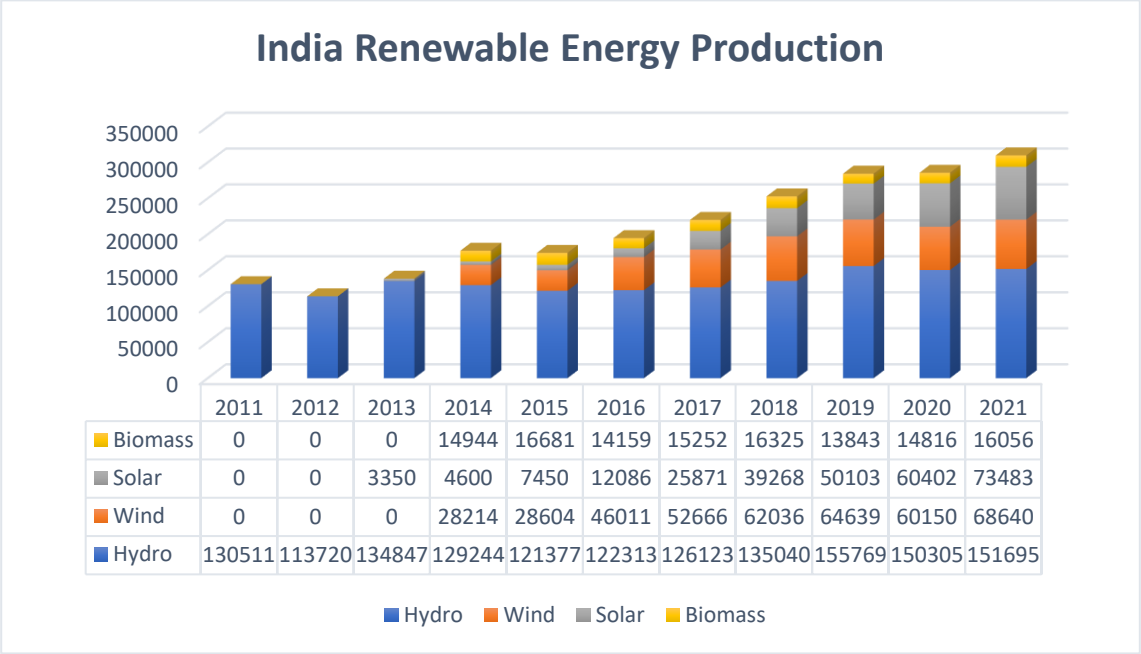
1.1.4 Bio-Gas

Biogas is environmental friendly and renewable source of energy. Biogas is produced by the waste food, manure, sewage, animal waste, crops residue, etc. All the organic and inorganic matter is collected in a closed container and no oxygen is provided to the container. This process takes place in the absence of oxygen where the microorganism

present on the waste food decomposes the organic matter by performing some chemical reactions. The gases released during the chemical reaction are known as biogas. These gases are not allowed to release in to the atmosphere as they can produce toxicity in the near areas, so, these gases are carried out through the pipelines in our homes to fulfil the daily energy consumption needs (Takase et al., 2022). Biogas can be produced easily without much investment; only organic matter is required in a large quantity. India has begun on an intensive energy transition journey, aiming for 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 and net zero by 2070. To meet the ambitious Renewable Energy targets and achieve energy self-sufficiency, locally accessible Renewable Energy alternatives must be optimally exploited. Modern bioenergy is one such option. With the country's enormous surplus of biomass and other trash, energy recovery from these resources is a possible alternative. Modern bioenergy is unusual in that it provides numerous social and environmental benefits in addition to clean fuels(*Ministry of New and Renewable Energy | Ministry of New and Renewable Energy | India*, n.d.).

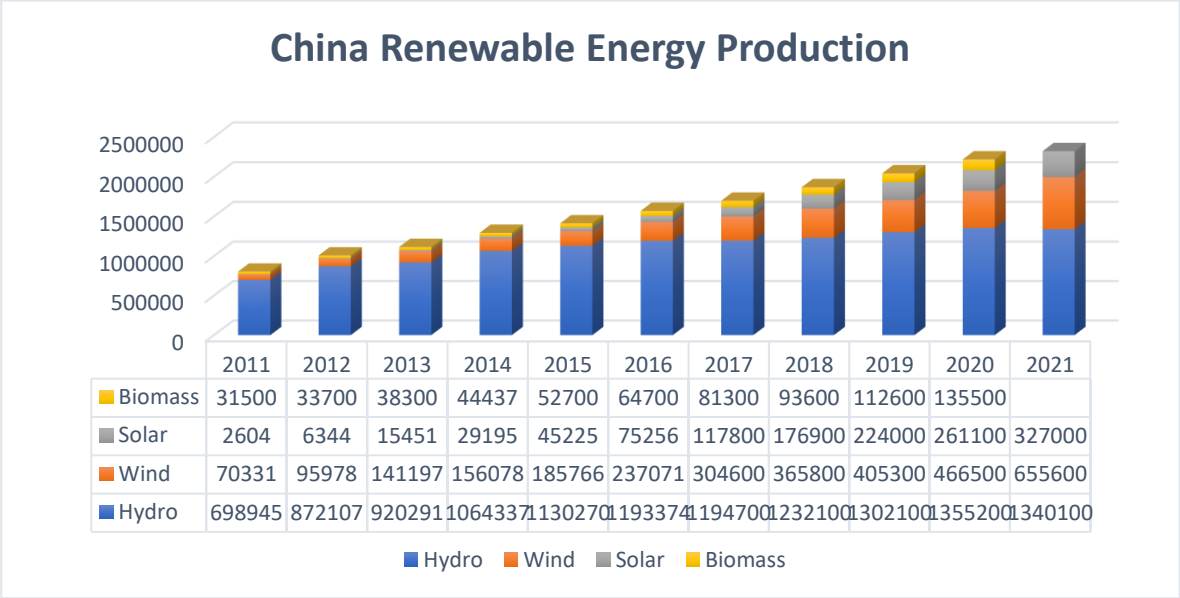
India is the second largest renewable energy producer in Asia and also finds place among the top ten in the world. The country is a major producer of hydroelectric power, with an installed capacity of 50GW in 2018. The major hydropower plants in India include the 1.45GW Sardar Sarovar project in Gujarat operated by Sardar Sarovar Narmada Nigam (*Green Power Information | Sardar Sarovar Narmada Nigam Limited*, n.d.), the 816MW Nagarjuna Sagar project in Telangana operated by TSGENCO, the 435MW Bansagar project owned by the Madhya Pradesh Water Resources Department, and others. In wind generation, India's major projects are the 1.5GW "Muppandal wind farm" in Tamil Nadu developed by the Tamil Nadu Energy Development Agency, the 1.27GW Jaisalmer Wind Park in Rajasthan developed by "Suzlon Energy", and the 528MW "Brahmanvel wind farm" developed by "Parakh Agro Industries" in Maharashtra. India is home to the 2GW Pavagada Solar Park in Karnataka owned by the "Karnataka Solar Power Development Corporation (KSPDCL)", the 1GW "Kurnool Ultra Mega Solar Park" in Andhra Pradesh owned by the "Andhra Pradesh Solar Power Corporation (APSPCL)", and the 648MW "Kamuthi Solar Power Project in Tamil Nadu" owned by Adani Power. Power generated by wind and solar facilities account for 29.8% and 22.8%, respectively, for the country's total renewable energy capacity (*Power Sector at a Glance ALL INDIA | Government of India | Ministry of Power*, n.d.)

Power produced in MW year wise from major Renewable sources of energy for India and China (*Renewable Energy Capacity Worldwide by Country 2022 | Statista*, n.d.) are shown in figure 2, 3 and 4.



	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Biomass	0	0	0	14944	16681	14159	15252	16325	13843	14816	16056
Solar	0	0	3350	4600	7450	12086	25871	39268	50103	60402	73483
Wind	0	0	0	28214	28604	46011	52666	62036	64639	60150	68640
Hydro	130511	113720	134847	129244	121377	122313	126123	135040	155769	150305	151695

Figure 2: Renewable energy Production in India (Renewable Energy Capacity Worldwide by Country 2022 | Statista, n.d.)



	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Biomass	31500	33700	38300	44437	52700	64700	81300	93600	112600	135500	
Solar	2604	6344	15451	29195	45225	75256	117800	176900	224000	261100	327000
Wind	70331	95978	141197	156078	185766	237071	304600	365800	405300	466500	655600
Hydro	698945	872107	920291	1064337	1130270	1193374	1194700	1232100	1302100	1355200	1340100

Figure 3 : Renewable energy Production in China (Renewable Energy Capacity Worldwide by Country 2022 | Statista, n.d.)

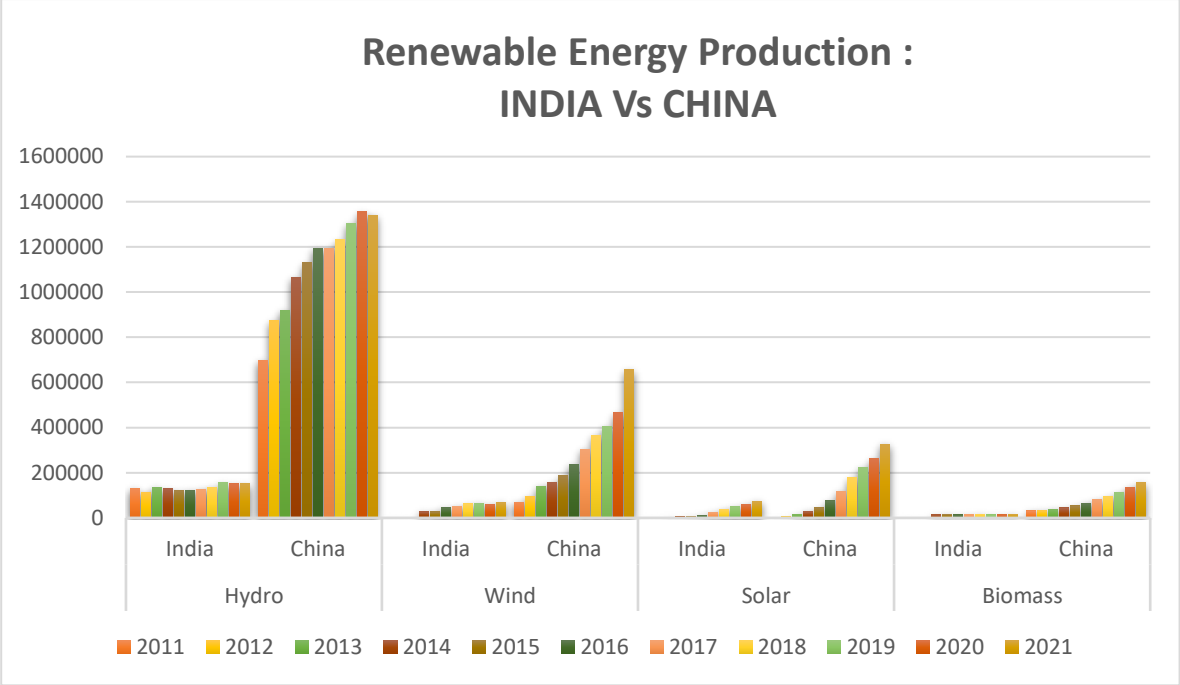


Figure 4: Renewable energy Production: India Vs China (Renewable Energy Capacity Worldwide by Country 2022 | Statista, n.d.)

1.2. Role of Renewable Energy in Sustainable Development Goals

Renewable energy plays a major role in mitigating climate change and greenhouse gas emissions which helps in attaining "United Nations Sustainable Development Goals (SDGs)". Renewable energy plays an important role while dealing with the sustainable development in India and is one of the important factor to sustain the" SDGs" (Gebara & Laurent, 2023). There is clear space for renewable energy in "SDG 7" which is "affordable and clean energy to all". Renewable has important role in "poverty reduction" (SDG 1) as it "promotes growth in economy", safeguarding "Sustainable cities" (SDG 11) by reducing pollution intensity and tackling "climate change" (SDG 13) by reducing the emissions of greenhouse gases. Uttarakhand has adopted the long lasting renewable energy in pursuance of the SDGS (Aghaloo et al., 2023). The dependence on the conventional exhaustible fuels has been lowered in Uttarakhand by adopting various renewable energy like solar, wind, hydro etc. and its technology in Uttarakhand. Uttarakhand has identified the renewable energy for its future sustainable development. The renewable energy and its schemes as per "UREDA (Uttarakhand Renewable Energy Development Agency)" is running five energy scheme , solar energy, hydro-energy, bio-energy, wind energy and solar thermal. These energy scheme reduces the dependencies of state on fossil fuels and promotes clean energy (*Government Of Uttarakhand*, n.d.). The renewable energy is cost effective and

clean in nature which helps in increasing the “quality of life (SDG 1)” especially in rural areas, resulting growth in economy and reduction in poverty. Renewable energy plays an important role in reducing the air pollution thus helps in battling the “climate change (SDG 13)” and provide a “sustainable answer for the development of Uttarakhand’s cities and communities (SDG 11)”. The renewable energy has been consistently put forward by the Uttarakhand’s government especially in hilly and rural areas to provide the energy access to all the people, decreasing the after effect of the energy to the environment and helps in meeting the SDGs (*Home | United Nations Development Programme*, n.d.). This state that renewable energy plays an important role both at local and at national level towards SDGs. This study is however limited to “Sustainable Development Goal 7” which “affordable and clean energy”.

1.3. Sustainable Development Goal 7

Goal 7 of the “Sustainable Development Goals (SDGs)” aims to “provide universal access to affordable, dependable, sustainable, and modern energy by 2030”. This objective must be met in order to address global energy concerns, mitigate climate change, and promote economic development. (*Home | United Nations Development Programme*, n.d.). Uttarakhand, a northern Indian state, is a prime example of a location having distinct energy dynamics and environmental sensitivity. Fulfilling “SDG 7” in Uttarakhand requires a methodical approach adapted to the state's unique peculiarities (Bisht, 2021). This work presents a ground-breaking hybrid approach that combines Machine Learning (ML) techniques and a “Hesitant Fuzzy Multi-Criteria Decision-Making (MCDM) model”, aided by Python programming, to identify the best renewable energy sources. The use of inclusive and robust datasets is critical in this search for informed decision-making. Uttarakhand, located in northern India, is known for its stunning natural beauty and various geographical features (Gebara & Laurent, 2023). This state has a large reservoir of renewable energy resources, with approximate coordinates spanning from 28.6139° N to 31.4404° N latitude and 77.0626° E to 81.0389° E longitude.

Figure 5: SDG 7 (Home | United Nations Development Programme, n.d.)

1.4. Renewable energy in Uttarakhand

Uttarakhand has a lot of solar energy potential because of its location in the Himalayan region, which gets a lot of sunlight all year. Because of the abundance of sun energy, the state is a great option for capturing solar power via photovoltaic systems and solar thermal technology. In addition, the hilly landscape of Uttarakhand provides tremendous wind energy potential, particularly at higher altitudes where wind speeds are constantly high. Wind power projects, such as wind farms and small-scale wind turbines, can use this natural resource to produce clean electricity (Chauhan et al., 2022). Hydropower is another important renewable energy source in Uttarakhand due to the numerous rivers and streams that originate in the Himalayas. Several hydroelectric power plants in the state create electricity by harnessing the energy of flowing water. These hydroelectric projects not only support the state's electricity needs, but they also help to cut carbon emissions, making Uttarakhand an environmentally beneficial destination. Uttarakhand's devotion to renewable energy is consistent with India's larger sustainable development goals and efforts to migrate to greener energy sources. As the state continues to capitalize on its plentiful sun, wind, and water resources, it has the potential to become a national model for sustainable energy practices, supporting both energy security and environmental conservation. The vast biomass resources in the state, such as agricultural wastes, forest

trash, and organic urban waste, serve as a valuable reservoir for bio-energy generation (*Government Of Uttarakhand*, n.d.). One significant path is biogas production via anaerobic digestion of organic matter, which can offer clean cooking fuel and electricity to rural homes while also contributing to energy security and environmental preservation. The government, research institutes, and organizations of Uttarakhand have been actively involved in expanding bio-energy research and initiatives, with an emphasis on improving biomass conversion technology and increasing crop yields for biofuel generation. Aside from lowering greenhouse gas emissions and promoting sustainable waste management practices, the use of bio-energy solutions can stimulate rural development, create job opportunities, and improve energy access in remote areas, all while aligning with the state's commitment to sustainable and eco-friendly energy practices.

Figure 6: Solar panels project in Uttarakhand [(Government Of Uttarakhand, n.d.)]

The energy situation in Uttarakhand is a mix of opportunities and problems. The state, which is located in the Himalayan area, has an abundance of renewable energy resources, including hydroelectric potential, adequate sunlight, and favorable wind patterns. However, the rough terrain, seasonal changes, and the need to protect the area's pristine ecosystem make energy planning a difficult effort. The hybrid model begins with the use of extensive datasets to solve these challenges and enable sustainable energy production. These datasets include historical energy consumption records, weather data, geographic information, and Uttarakhand-specific socioeconomic indicators (Bahuguna et al., 2023). Historical energy consumption data is essential for identifying temporal fluctuations in

energy demand by providing insights into prior trends and patterns. Furthermore, meteorological databases capture local weather variables, such as solar radiation levels and wind speeds, which are critical for estimating renewable energy potential. These datasets allow ML algorithms, such as time-series analysis and regression models, to produce accurate predictions of energy demand and renewable energy generation patterns. Solar irradiance records, for example, aid in modelling the diurnal and seasonal fluctuations in solar energy potential, whereas wind speed data aids in calculating wind power generating possibilities. In addition to environmental parameters, the model incorporates socioeconomic and demographic statistics. These statistics collect information on population density, economic growth, and social acceptance variables, allowing towns to assess their readiness to embrace renewable energy solutions. The integration of these datasets allows the hybrid model to account for the human factor in decision-making, which aligns with "SDG 7's" commitment to universal energy access. The hybrid model's ML component pulls actionable insights from these datasets. ML algorithms can identify important drivers of energy demand and supply by analyzing historical trends and correlations between variables. This data-driven strategy not only improves energy prediction accuracy but also finds critical elements that influence renewable energy choosing (Salcedo-Sanz et al., 2018). The "Hesitant Fuzzy-MCDM model" enhances decision-making by combining multi-criteria evaluations. It contains a variety of datasets, including economic feasibility, environmental impact, social acceptance, and technological feasibility. Because these datasets are inherently uncertain and frequently qualitative, the "hesitant fuzzy set" theory is a powerful tool for more flexibly capturing decision-makers' preferences and uncertainties. When the results from the ML and "Hesitant Fuzzy-MCDM" components are combined, a thorough ranking of renewable energy choices specific to Uttarakhand is produced (Büyüközkan et al., 2018b). These recommendations are based on data-driven insights and reflect a comprehensive evaluation of criteria that includes both quantitative and qualitative characteristics.

This novel research motivated by the data developed from the experts is oriented towards the "SDG 7" which is proposed to fulfil the energy requirement of Uttarakhand. The filtered data set from the "Machine Learning" can suggest the "Decision Makers" to consider the sustainable energy system for a specific region. The suggested model can be efficiently used in other region by taking different dataset and factors as per the geographical, socio-economic, cultural, and legal and others conditions of that region.

2. Research Problem

Uttarakhand a northern state which is known for its natural sites and serene weather, has to adopt sustainable energy system in order to fulfill the requirement of SDG 7 which is "ensuring access to affordable and clean energy for all". In spite of having a handsome amount of renewable energy reservoir Uttarakhand is lacking in exploring these resources such as solar energy, wind energy etc. considering the state geographical, cultural, social, and economic. The selection of a user friendly renewable energy source which will meet the growing energy demand, prevent the environment from hazardous fossil emissions, accelerate economic growth and sustain cultural and social diversity are the major challenges. The inclusions of appropriate criteria and sub-criteria to reduce the uncertainties, use of past data add more problem in the current energy decision making system. The problems stated above makes necessary to have a comprehensive solution which will consider all the factors regarding renewable energy selection in Uttarakhand. The current energy system finds difficult to proceed towards SDG7.

These problems has been considered and this research proposes a unique hybrid model which integrates "Machine Learning technique" and "Fuzzy-MCDM" method in a hesitant environment. The hesitancy will remove the uncertainty, vagueness and error in the system. The complex computation involved in the process is reduced by using python programming. The energy consumption complexity, accessibility of renewable energy sources, economic feasibility, environmental impact and others factors are proposed to be taken into account. An in depth decision making system should be developed which should have qualitative data (linguistic) type which can navigate decision makers, policy makers and stakeholders for the suitable energy selection in Uttarakhand. For the advancement of the SDG 7 "affordable and clean energy for all" the selection model should considered and respect the distinct features of the specific area.

3. Literature Review

"Ensuring access to clean energy for everyone" and reducing the emissions to the air are the important features of renewable energy (Agency et al., 2021). The selection of best renewable energy for a specific region is a challenge as there are number of factors that are need to be consider like socio-economic, environmental, financial and other implications associated (Sitorus & Brito-Parada, 2022). A large number of research has been carried in renewable energy sector and its selection process. Various researchers has proposed their model and the tools through this can be achieved. "Multi Criteria Decision Making

(MCDM)" is one of the important tool which is widely used in decision making problem. It can be used to calculate the weight and ranking of the in the selection process system (Sitorus & Brito-Parada, 2022). The "Analytic Hierarchy Process", "technique for order preference by similarity to ideal solution (TOPSIS)", and the "VIseKriterijumska Optimizacija i Kompromisno Resenje (VIKOR)" method which has been regularly used in this field. (Sareriya et al., 2022) successfully conducted ranking of renewable energy in India using AHP. Abdul D. et al. assesses and evaluate criteria weight for the decision makers in Pakistan. A similar type of research is carried out by (Percy & Edwin, 2023) for evaluating the criteria and alternatives in the different blocks of the region using AHP. (Petrov, 2021) uses integrated AHP Shannon Entropy in the MOORA evaluation for the renewable energy project. A similar research is carried by (Sedghiyan et al., 2021) in Iran using AHP, TOPSIS and SAW for finding the most suitable criteria and renewable energy in five climate zones. Bhowmik C. et. al. use AHP for carrying the research in identifying the smart cities in the western part of the India.

The MCDM approach when applied to the real life situation can yield uncertain, unclear, ambiguity. These can be tackled by using fuzzy sets along with the MCDM technique. There are number of instances when these two techniques are integrated and has been used in the energy selection process. (Quteishat & Younis, 2023) uses "Fuzzy-TOPSIS" and shows that ambiguity and uncertainty was successfully dealt while finding the most appropriate renewable energy. (Quteishat & Younis, 2023) uses "Fuzzy TOPSIS and Fuzzy PROMETHEE" to compare the two techniques after ranking the RES. (Quteishat & Younis, 2023) uses" Fuzzy AHP and Fuzzy TOPSIS" to find the most important factors fo calculating the rank of renewable energy in India. (Xin et al., 2023) successfully used "interval type-2 fuzzy sets (IT2FSs)" & TOPSIS for the selection of renewable energy.

The decision making can be more efficient if it is done in hesitant environment where the decision maker will have hesitancy to give his/her opinion. The same has been discussed by (Büyüközkan et al., 2018a) **"**Hesitant Fuzzy Linguistic set" along with "AHP and COPRAS" working on several criteria and sub-criteria while meeting the "Sustainable Development Goals". (Yang et al., 2023) uses interval-valued hesitant fuzzy elimination and choice expressing reality (IVHF-ELECTRE II) to evaluate the renewable energy alternative which can be beneficial for national policy makers. (Çolak & Kaya, 2017a) **,** uses "type-2 fuzzy sets and Hesitant fuzzy TOPSIS" and successfully calculated the weight of all the criteria to find the suitable renewable energy and then performed the sensitivity

analysis.

The literature table is showing the different types of "MCDM and fuzzy technique" and the different environment used in the selection problem for renewable energy and the associated technology.

Table 2: Literature Review Table

S. No.	Author/ Country	Title	Year	Research Area	Methodology (ies)	Finding(s)
1	(Sitorus & Brito-Parada, 2022) United Kingdom	"The selection of renewable energy technologies using a hybrid subjective and objective multiple criteria decision making method"	2022	Renewable Energy in Industries	Fuzzy-MCDM	The Hybrid model successfully ranked the renewable energy in mining industry by considering various criteria
2	(Sheth et al., 2022) Canada	"Selection of Sustainable Energy Alternatives from Indian Context"	2022	Renewable Energy Selection	Fuzzy AHP and Fuzzy TOPSIS	The proposed model was able to find the most important factors for calculating the rank of renewable energy in India
3	(Aghaloo et al., 2023) Japan	"Optimal site selection for the solar-wind hybrid renewable energy systems in Bangladesh using an integrated GIS-based BWM-fuzzy logic method"	2023	Solar-Wind Hybrid Renewable Energy Systems (SWHRESs)	GIS-based BWM-Fuzzy Logic Method	The study shows that the proposed technique can be used for decision making in SWHRESs meeting sustainable Development Goals 7 in Bangladesh
4	(Geetha et al., 2022) India	"An adoptive renewable energy resource selection using Hesitant Pythagorean Fuzzy DEMATEL and VIKOR methods"	2022	Renewable Energy selection	Hesitant Pythagorean fuzzy (HPF) & DEMATEL and VIKOR	HPF-AHP and HPF-VIKOR were able to identify and evaluate the criteria and alternatives in renewable energy selection
5	(Pathak, Sharma, &	"Prioritization of Renewable Energy Alternatives by	2022	Renewable Energy selection	Analytical Hierarchy Process	Hydro, solar and wind energy were

	Chougule, 2022b) India	Using Analytic Hierarchy Process (AHP) Model: A Case Study of India"				successfully ranked using AHP method
6	(Chou et al., 2021) Taiwan	"Renewable energy selection based on a new entropy and dissimilarity measure on an interval-valued neutrosophic set"	2021	Renewable Energy selection	Neutrosophic fuzzy and ENTROPY	The unique model developed was able to find the criteria weight and evaluate them to select the renewable energy in Taiwan
7	(Abdul et al., 2022) Pakistan	"Prioritization of renewable energy source for electricity generation through AHP-VIKOR integrated methodology"	2022	Renewable Energy for Electricity	Integrated Analytical Hierarchy Process and VIKOR	The assessment and evaluation of criteria and weight were helpful for the policy makers in Pakistan
8	(Tekin et al., 2021) Turkey	"Selection of renewable energy systems sites using the MaxEnt model in the Eastern Mediterranean region in Turkey"	2021	Renewable Energy site selection	Maximum Entropy Model (MaxEnt) and Geographical Information systems (GIS)	The model was able find the suitable site for the renewable energy in Turkey
9	(Petrov, 2021) Bulgaria	"Renewable energies projects selection: block criteria systematization with AHP and Entropy-MOORA methods in MCDM"	2021	Renewable Energy Project Selection	Analytical Hierarchy Process Shannon Entropy in the MOORA evaluation	The integrated approach was successfully used for assessment and evaluation of Renewable energy project
10	(Pan & Wang, 2021) China	"An Enhanced Technique for Order Preference by Similarity to Ideal Solutions and its Application to Renewable Energy Resources Selection Problem"	2021	Renewable Energy selection	interval type-2 fuzzy sets (IT2FSs) & TOPSIS	The integrated model was successfully used for the selection of renewable energy
11	(Sedghiyan et al., 2021) Iran	"Prioritization of renewable energy resources in five climate zones in Iran using AHP, hybrid AHP-	2022	Renewable Energy selection	AHP, TOPSIS and SAW	The MCDM approach was successfully conducted for finding the most suitable criteria and renewable

		TOPSIS and AHP-SAW methods"				energy in the five climate zones in Iran
12	(Thu et al., 2022) Mayanmar	"Program for the Selection of Sites to construct Renewable Energy Plants based on the Method of Analytic Hierarchy Process (AHP)"	2022	Renewable Energy Selection Site	AHP, C++	The technique was successfully used to form a computer program for the renewable energy plant establishment in Myanmar
13	(Niu et al., 2020) China	"Prioritization of Renewable Energy Alternatives for China by Using a Hybrid FMCDM Methodology with Uncertain Information"	2022	Renewable Energy selection	Interval-valued hesitant fuzzy elimination and choice expressing reality (IVHF-ELECTRE II)	The research provides a viable process for evaluating and assessing the criteria and alternatives
14	(Elleuch et al., 2021) Tunisia	"Energy sources selection for sustainable energy planning using fuzzy multi-criteria group decision-making approach: Tunisia Case Study"	2021	Renewable Energy selection	fuzzy multi-criteria group decision making	The various selection criteria were successfully evaluated using sensitivity analysis
15	(Percy & Edwin, 2023) India	"Feasibility assessment and prioritization of renewable energy resources: towards an energy transition for the society and the environment—a case study approach"	2023	Sustainability and renewable energy	Analytical Hierarchy Process	Research was successfully evaluated different criteria and evaluated the best renewable energy source in the different blocks of the region
16	(You & Hou, 2023) China	"A novel consensus model with probabilistic linguistic preference relation for the utilization mode selection of renewable energy sources"	2023	Machine Learning	probabilistic linguistic preference relations (PLPRs)	The proposed model successfully ranked the renewable energy source in the Jinsha river in China
17	(Saleem et al., 2021) Pakistan	"The prioritization of renewable energy technologies in Pakistan: An urgent need"	2021	Renewable Energy selection	Analytical Hierarchy Process	The research was able to identify the most suitable criteria and then ranked the most

						appropriate renewable energy
18	(Goswami et al., 2022) India	"Selection of a green renewable energy source in India with the help of MEREC integrated PIV MCDM tool"	2022	Renewable Energy selection	integrated MEREC-PIV MCDM	Research was successfully conducted to rank the renewable energy power plant in India
19	(Chiranjib et al., 2023) India	"Selection of optimum renewable energy sources under smart city environment for energy management and planning: An eclectic decision"	2023	Green Energy Selection/ Sustainable Development	Analytical Hierarchy Process	The research successfully conduct to identify the green energy in smart cities in the western part of India
20	(Moreno Rocha et al., 2022) Spain	"Implementation of the hierarchical analytical process in the selection of the best source of renewable energy in the Colombian Caribbean region"	2022	Renewable Energy and Group decision making	Analytical Hierarchy Process	The various renewable energy were ranked according to several criteria and sub-criteria based on expert opinion
21	(Wang et al., 2021) Vietnam	"A multicriteria decision-making model for the selection of suitable renewable energy sources"	2021	Renewable Energy selection	Grey Analytic Hierarchy Process (G-AHP) method and the Weighted Aggregates Sum Product Assessment (WASPAS)	The performance score of the various renewable energy source was successfully calculated using integrated MCDM method.
22	(Quteishat & Younis, 2023) Jordan	"Strategic Renewable Energy Resource Selection Using a Fuzzy Decision-Making Method"	2023	Renewable Energy selection	Fuzzy Topsis	The ambiguity and uncertainty was successfully dealt while finding the most appropriate renewable energy
23	(Joshi et al., 2023) India	"TOPSIS based Renewable-Energy-Source-Selection using Moderator Intuitionistic Fuzzy Set"	2023	Renewable Energy selection	moderator intuitionistic fuzzy set (MIFS) Topsis	The research was able to find that the proposed model is superior to the existing one for selecting the

						renewable energy
24	(Yontar, 2023) Turkey	"Selection of suitable renewable energy sources for Turkey: SEM–COPRAS method integrated solution"	2023	Renewable Energy selection	COPRAS	The criteria and sub-criteria were selected based on expert opinion which were used to calculate the weight and then best renewable energy was identified
25	(Shokatpour et al., 2022) Iran	"Renewable Energy Technology Selection for Iran by Using Multi Criteria Decision Making"	2022	Renewable Energy selection	TOPSIS	The research was able to rank the conventional renewable energy source for power generation
26	(Pathak, Sharma, & Chougule, 2022a) India	"Prioritization of Renewable Energy Alternatives by Using Analytic Hierarchy Process (AHP) Model: A Case Study of India"	2022	Renewable Energy selection	Analytical Hierarchy Process	The priority weight percentage was calculated of different renewable energy source to find the most suitable RES
27	(Gupta et al., 2023) India	"Selection of renewable energy sources: a novel VIKOR approach in an intuitionistic fuzzy linguistic environment"	2023	Renewable Energy selection	trapezoidal intuitionistic fuzzy linguistic Einstein's interactive weighted average (TrIFLEIWA) VIKOR	The research was apply on real world problem removing the uncertainty while selection the most appropriate renewable energy source
28	(Pathak, Sharma, Chougule, et al., 2022) India	"Prioritization of barriers to the development of renewable energy technologies in India using integrated Modified Delphi and AHP method"	2022	Renewable Energy selection	Modified Delphi & AHP	The research was successfully able to prioritize the different barriers to the sustainable development of renewable energy
29	(Su et al., 2022) China	"A Fuzzy-Social Network Multi-criteria Group Decision-Making Framework for Selection of	2022	Renewable Energy selection	multi-criteria group decision-making (MCGDM) social network	The research shows that the proposed model was suitable for the decision

		Renewable Energy Project: A Case of China"			analysis (SNA) and hesitant probabilistic fuzzy set (HPFS)	makers in REP in China
30	(Mishra et al., 2022) India	"Fermatean fuzzy copula aggregation operators and similarity measures-based complex proportional assessment approach for renewable energy source selection"	2022	Renewable Energy selection	Fermatean fuzzy set & complex proportional assessment (COPRAS)	The integrated Fermatean fuzzy-COPRAS approach using the Archimedean copula-based Maclaurin symmetric mean operator was able to rank the renewable energy
31	(Ebrahimi, 2018) Tehran	"A fuzzy MCDM-based approach for renewable energy technologies prioritisation"	2018	Renewable Energy selection	Fuzzy TOPSIS and Fuzzy PROMETHEE	The result was able to compare the two techniques after ranking the RES
32	(Abdullah & Najib, 2017) Malaysia	"Interval Type-2 fuzzy analytic hierarchy process for sustainable energy sources selection"	2017	Renewable Energy selection	Type-2 fuzzy analytic hierarchy process (IT2 FAHP)	The linguistic data were evaluated under the guidance of expert opinion to rank the renewable energy
33	(Turgut & Tolga, 2018) Turkey	"Fuzzy MCDM methods in sustainable and renewable energy alternative selection: Fuzzy VIKOR and fuzzy TODIM"	2018	Renewable Energy selection	Fuzzy-Multi Criteria Decision Making (VIKOR and TODIM)	The research was successfully able help the decision makers for opting the suitable RES
34	(Büyüközkan et al., 2018b) Turkey	"A novel renewable energy selection model for United Nations' sustainable development goals"	2018	Renewable Energy selection	"HFL Analytic Hierarchy Process HFL COmplex PRoportional ASsessment (COPRAS) and SDGs"	The research was able to successfully implement the model in decision making which help the policy makers in RES
35	(Bhowmik et al., 2018) India	"Green energy sources selection for sustainable energy planning using multi-criteria decision-making approach"	2018	Renewable Energy selection	SWOT (Strength, Weakness, Opportunities, and Threats) and an integrated	The proposed hybrid model was able to find the best alternative Green Energy Source

					Entropy-Technique for Order of preference by Similarity to Ideal solution (TOPSIS)	
36	(Niu et al., 2020) China	"Prioritization of renewable energy alternatives for China by using a hybrid FMCDM methodology with uncertain information"	2020	Renewable Energy selection	interval-valued hesitant fuzzy elimination and choice expressing reality (IVHF-ELECTRE II)	The proposed model successfully evaluate the renewable energy alternative which can be beneficial for national policy makers
37	(Salcedo-Sanz et al., 2018) Spain	"Feature selection in machine learning prediction systems for renewable energy applications"	2018	Machine learning Feature Selection	Coral Reefs Optimization algorithm with Substrate Layer	The feature prediction system was improved by 20 percentage with the proposed technique
38	(Büyüközkan et al., 2020) Turkey	"Integrated Fuzzy Multi Criteria Decision Making Approach for Sustainable Energy Technology Selection"	2020	Renewable Energy selection	"fuzzy AHP (Analytical Hierarchy Process), fuzzy VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje) and fuzzy TOPSIS"	The alternate sustainable energy is prioritize using the propose technique and then compare by using fuzzy TOPSIS
39	(Büyüközkan et al., 2020) Pakistan	"An integrated Delphi-AHP and fuzzy TOPSIS approach toward ranking and selection of renewable energy resources in Pakistan"	2019	Renewable Energy selection	Delphi-analytical hierarchy process (AHP) and fuzzy technique and Fuzzy TOPSIS	The research direct sustainable energy planning by ranking renewable energy for electricity generation
40	(Saraswat et al., 2021) India	"Development of Assessment Model for Selection of Sustainable Energy Source in India: Hybrid Fuzzy MCDM Approach"	2021	Renewable Energy selection	Fuzzy Analytic Hierarchy Process (F-AHP) & Fuzzy Weighted Aggregated Sum Product Assessment	Weight of the alternative were calculate by fuzzy AHP and rankings were obtained by fuzzy WASPA and then

					(F-WASPAS) VIKOR, TOPSIS, and PROMETHEE - II.	compared by different MCDM techniques
41	(Kabak & Dağdeviren, 2014) Turkey	"Prioritization of renewable energy sources for Turkey by using a hybrid MCDM methodology"	2014	Renewable Energy selection	BOCR (Benefits, Opportunities, Costs and Risks) and ANP (Analytic Network Process)	The Most suitable renewable energy was suggested was by the proposed techniques
42	(Sheth et al., 2022) India	"Selection of Sustainable Energy Alternatives from Indian Context"	2022	Renewable Energy selection	Fuzzy analytic hierarchy process (AHP) & Fuzzy TOPSIS	The most important criteria was identified and then prioritization was done with proposed technique
43	(Jha & Puppala, 2017) India	"Prospects of renewable energy sources in India: Prioritization of alternative sources in terms of Energy Index"	2017	Renewable Energy selection	Analytical Hierarchy Process	The renewable energy is evaluated based on the energy index calculated by evaluating alternative over a range of environmental and technical criteria
44	(Çolak & Kaya, 2017b) Turkey	"Prioritization of renewable energy alternatives by using an integrated fuzzy MCDM model: A real case application for Turkey"	2017	Renewable Energy selection	AHP, type-2 fuzzy sets and Hesitant fuzzy TOPSIS	The research successfully calculated the weight of all the criteria to find the suitable renewable energy and then performed the sensitivity analysis
45	(Yontar, 2023) Turkey	"Selection of suitable renewable energy sources for Turkey: SEM-COPRAS method integrated solution"	2023	Renewable Energy selection	structural equation modelling (SEM) & COPRAS	Ranking of different renewable energy is carried out successfully in Turkey with the help of

						proposed technique
46	(Chatterjee & Kar, 2018) India	"A multi-criteria decision making for renewable energy selection using Z-numbers in uncertain environment"	2018	Renewable Energy selection	Complex Proportional Assessment (COPRAS) Z-number model fuzzy	The weight is calculated and ranking is obtained successfully followed by comparison of the proposed model with other MCDM techniques

4. Research Gap

There are enormous number of literature covering the assortment of renewable energy, still there are some gaps which needs to be addressed. Followings are the research gaps:

- The prioritizing of renewable energy has been carried out in the country level and not in the state or local level. No such selection process has been carried out in Uttarakhand.
- The social, economic, environment, legal, technical and other impacts on renewable energy selection needs to be addressed more and there is enough research awaited in this field especially in regions having geographical and cultural diversity.
- Research has been carried separately on "Fuzzy MCDM/Machine Learning for renewable energy selection". There is clear research gap which integrates all the approaches while approaching towards sustainable development Goals.
- The selection of renewable energy has been done by computing different criteria and alternatives using fuzzy mathematics in different environment. This task is complicated which can creates error and there is a scope of advanced computer programing in this regard.
- The energy selection related models or process used in the literature are complicated and are not easy to understand for the policy makers especially for the regions where the landscapes changes abruptly. Moreover usage of quantitative data quantifies the problem more. The usage of qualitative data for the integrated approach can make it use friendly to the policy makers or others.

5. Research Objectives

Followings are the objectives based on the gap found from the literature:

- **Renewable energy selection model at state level:** to construct and developed a regional level hybrid model for the selection of renewable energy which can caters the energy requirement of local people keeping in mind the geographic and cultural condition of the region.
- **Impact of economic feasibility, environmental consequence, social recognition, technological viability, legal framework comprehensive evaluation:** to propose a transparent and fair evaluation process for the selection of main criteria (example social, economic, environment etc.) and their impact on the energy selection taking into consideration of geographical and cultural diversity of Uttarakhand.
- **Amalgamation of Fuzzy in Hesitant environment, MCDM and Machine Learning Approaches:** an advanced hybrid model is proposed to fulfill the research gap which will integrates the "Hesitant Fuzzy-MCDM" with the machine learning technique using high level programming for the selection of sustainable energy working towards Sustainable Development Goals (SDGs).
- **Implementation of high level computer programming language:** to find an advanced computer programing technique for the selection process in order to reduce the complexities and errors associated with the computation of fuzzy problems in various steps.
- **Constructing a flexible Hybrid Models with Qualitative Information:** to propose a user-friendly sustainable energy selection process which will work on qualitative data (linguistic data suggested by the experts) and makes it understandable for the policy makers in the regions where the geography and culture changes rapidly.

6. Methodology

A three phase hybrid fuzzy model is proposed to be used to prioritize the renewable or sustainable energy source in Uttarakhand. The integrated model used for this are: "Hesitant Fuzzy MCDM approach and Machine Learning" working in the direction of SDG 7 in order to "ensure affordable and clean energy for all". The different criteria and sub-criteria

are selected by a survey of questionnaire based on the different “social, political, economic, environmental and legal” and other factors under the guidance of energy experts and with the help of literature history. The sub-criteria which align with the “SDG 7” are selected using “Machine Learning technique”. The various criteria are evaluated and their weight is calculated using “Hesitant Fuzzy-MCDM” and then ranking is obtained for the available renewable sources of energy in Uttarakhand. The “sensitivity analysis” is performed to check the adeptness of the proposed model. The complex computation involved in the process is done with the help of python programming which also reduces the possibility of the error. The advantage of using “Hesitant Fuzzy” is that it deals with the uncertainty, vagueness and ambiguity which is very certain in real life problem. Machine Learning filtering technique remove the uncertainty while electing the criteria from a large number of group. The suggested five phase novel integrated model for the research as shown in figure is discussed below.

Phase I: It consists the setting of goal of the research, which is to identify the suitable renewable sources of energy in Uttarakhand considering the above mentioned socio-economic, political, environmental and other factors. It also consists the objectives which comes after going through the literature and gap as discussed in the objective section.

Phase II: This includes one of the most crucial part of the research which consists selection of criteria and alternatives. The alternatives are selected according the available renewable sources in Uttarakhand such as solar energy, hydro-energy, wind energy, biomass energy etc. The selection of main criteria and sub-criteria is a tedious task, number of sub-criteria are falling under the main criteria which needs to be compressed, keeping in mind that all the criteria fulfilling the requirement of SDG 7. The numbers of criteria are selected from the literature review and from the survey conducted under the supervision of energy experts and then reduced to an optimum value using Machine Learning Technique. The data from the survey will be conducted in linguistic form which will be transformed into fuzzy sets through linguistic table.

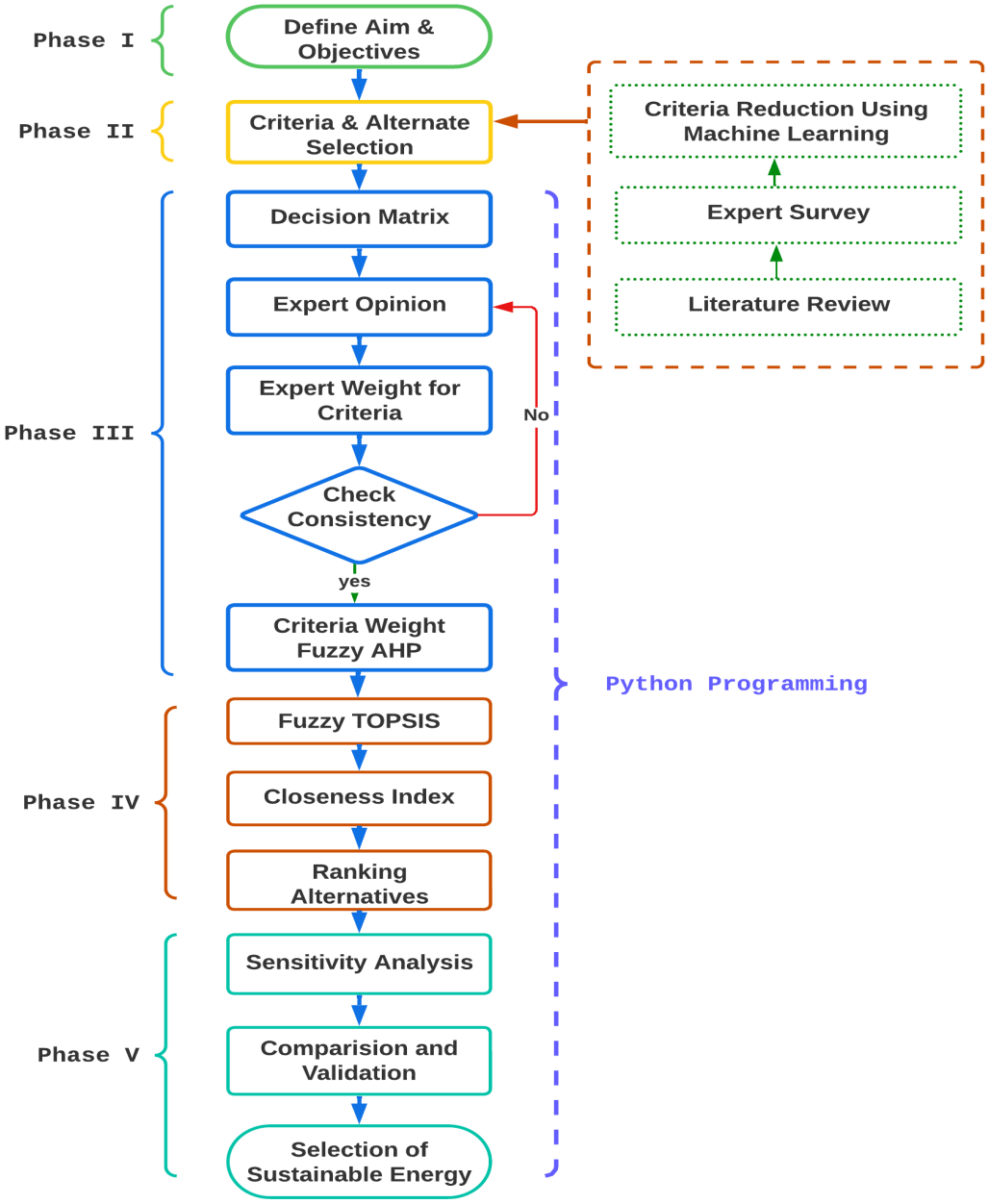


Figure 7 : Proposed Research Model

Phase III: A decision matrix is then formed while applying the expert value in order to calculate the weight of the main criteria and sub-criteria. The matrix is then filled with the weight given by the experts which is then solved to check the consistency ratio (CR). If CR falls within the range then the aggregate weight of the criteria will be used for calculating the closeness index through fuzzy TOPSIS.

Phase IV: In this phase the rankings of the alternatives is obtained using Fuzzy-TOPSIS. The aggregate weight of the criteria is taken in TOPSIS and the closeness index is identified while computing it through the python programming.

Phase V: This final steps involves the effect of weight of main criteria on the ranking of

the various alternatives which are various renewable energy sources in Uttarakhand. This process is known as sensitivity analysis and is used to deal with the uncertainty associated with the various factors while prioritizing the renewable sources of energy. The final ranking is obtained for those which will have least variation while varying the various criteria.

7. Implications

- The "Sustainable Development Goal 7" aims to "ensure affordable, reliable, sustainable and modern energy for all". The proposed renewable selection model while considering SDG 7 have important implications which are discussed as below:

- Availability of energy for every section: This includes the availability of energy to every individual of Uttarakhand state which align with SDG 7's goal of "universal access to clean and affordable energy to all".

- Energy for poor: The cost reduction in the energy can be achieved by selecting renewable sources of energy which is suitable for off-grid and hilly rural areas while helping in reducing poverty in Uttarakhand which is SDG 1 aim "poverty reduction".

- Switch to green energy: The carbon emissions through the use of fossil can be significantly reduced as the proposed study suggested renewable energy access, which helps in mitigating the climate change (SDG 13).

- Sustainable Ecology: The model take the various environmental factors while prioritizing the renewable energies which help to protect the local resources while conserving the ecology and reducing the after effect on the environment contributing to quality life on land (SDG 15).

- Growth in economy: The suggested research is oriented towards growth in economic which can create new jobs in the region and helped in achieving the SDG 8 which is "Decent Work and Economic Growth".

- Local involvement: The proposed research encourages local public involvement in energy decision-making, moving towards SDG 16 which is "Peace, Justice, and Strong Institutions".

- Efficacy of energy: The proposed model focuses on the use of "efficient energy technologies and practices" by eliminating the wastage of energy and helps in achieving

the SDG 12 “Responsible consumption and production”. It also encourage the latest technology which align with the SDG 9 which is “Industry, Innovation, and Infrastructure”.

- Sensitive to natural catastrophe: Uttarakhand is a state which is very sensitive to natural disaster calamities, the proposed model can provide a suitable solution while tackling such problems in advance thus contributing towards SDG 11 which is “Sustainable Cities and Communities”.

- Better healthcare and value added Education: The use of renewable energy by the rural people improves their health and promotes quality education which aligns with the SDG 3 and SDG 4.

- No gender discrimination: The proposed user friendly model can be useful for the women which will promote “gender equality” which help in attaining the SDG 5.

The proposed renewable energy selection model play an important role while proceeding towards SDGs by tackling accessibility of energy, socio-economic problem, conservation of ecology, economic growth and social wellbeing in Uttarakhand. The issue highlighted above aligns with the 2030 targets of achieving a sustainable future in energy area.

8. Limitations

The proposed model is having various implications which are already discussed above. The implications are attached with some challenges and disadvantages which are discussed below:

- Accessibility of quality data: The sustainability of the model relies on data availability and its quality. It includes the various socioeconomic, geographical and others factors which makes the data collection and its record a challenging task and can affect the efficiency of the model.

- Information gap: The data gap can be issue while dealing with the model as Uttarakhand has diverse geographical and cultural areas. The extreme hilly area can increase the problem more and can affect the model performance.

- Challenging Physical Landscape: Uttarakhand is a hilly state in which more than 80% area is covered by mountains. The establishment of renewable energy and its technologies is always a challenge for the proposed model.

- Periodic Variance: Uttarakhand lies between 28^{o} 44' & 31^{o} 28' N Latitude and 77^{o} 35' & 81^{o} 01' East longitude and has substantial seasonal variations which can affect the

performance of the proposed model.

- Variation in energy resources: The proposed may not able to deal the variation in the renewable energy sources because of the seasonal variation and other phenomenon encountered in Uttarakhand. The variation may be irregular availability of solar, wind, hydro and other energy.
- Societal and human conduct: Uttarakhand is a state of diverse culture, the research have considered the social problem but may face challenge while dealing with the human conduct in renewable energy selection.
- Difficult Decision-Making Method: Although the research claim it as user friendly still it may be difficult for those who have very little knowledge and expertise of the techniques used in the model.
- Rule and Supervisory Concerns: Uttarakhand is a state of changing rules and regulation and the research may not able to cover these changes such as grants, supports, incentives and constraints.
- Incorporation Problems: The addition of diverse renewable energy into the current energy structure is difficult and can demand considerable funds. The suggested research may not able to deal the stated problem.

In spite of the above limitations, the selection model based on "Hesitant Fuzzy-MCDM and machine learning in Python" can be an efficient tool for guiding Uttarakhand decision-makers towards sustainable energy option.

9. Conclusion and Scope

The proposed model for the selection of renewable energy using "Hesitant Fuzzy-Multi-Criteria Decision-Making (Hesitant Fuzzy-MCDM) machine learning" with the help of python programming provide a unique way to attain the "sustainable development goals 7" in Uttarakhand. This novel selection model has the potential to search the sustainable energy while dealing with the transient conditions like landscape, ecology, socio-economic etc. The selection criteria are selected from the in depth literature survey and form the literature survey conducted under the supervision of experts in energy sector. The large number of the selection criteria are reduced using machine learning reduction method. The linguistic data are then used to find out the weight of all criteria using "Fuzzy-MCDM technique" and then this weight is used to find the rankings of the alternatives which are

different renewable sources of energy (solar, wind, hydro, biomass, solar thermal). The sensitivity analysis is also proposed to be carried out in order to check the robustness of the model. The whole process is carried out in five phases and the computation is to be done using python programming. As discussed in the section 7, the model has number of implications like energy access, poverty reduction, health, growth in economy etc. aligning with the various "sustainable development goals (SDGs)" and highlights the important role of Uttarakhand people in energy decision making. It is also necessary to consider the limitations of the proposed model which have been discussed in the section 8. The overcoming of these challenges provide an opportunity to carry further research or extend the proposed research. The proposed model can be made more effective by considering the challenges like accessibility of the quality data, information gap, periodic variation, human conduct, and variation in renewable energy and many more. Uttarakhand faces extreme geographical, changing socio-economic, unpredictable human conduct, transient environment and uncertain legal energy framework and to attain "SDG 7" renewable energy can overcome these challenges for meeting the energy requirement of the state especially people of hilly or remote regions. The research navigates the importance of quality data base type decision making to opt the green energy for the sustainable energy future. The model can provide a robust structure for the state including local people, policy makers, and decision makers to proceeds towards "SDG 7" while selecting the best renewable sources of energy. It also provides a way to aware Uttarakhand state about the importance of "Sustainable Development Goals (SDGs)" and can help the state in its Sustainable development.

10. Proposed Month-wise plan of work and targets to be achieved

GOALS	Year I (2022-23)		Year II (2023-24)		Year III (2024-25)	
	Semester I	Semester II	Semester III	Semester IV	Semester V	Semester VI
Course Work						
Literature Review						
Preparing PhD Title						
Research Publication						
Data Collection						
Data Analysis						
Thesis Proposal						
Pre Ph.D. Seminar						
Thesis Writing						
Presentations						
Drafting a Thesis						
Thesis Completion						
Ph.D. Defence						

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